NOV 10 '79

Natl. Acad. Engr.

CIVIL Aviation Research and Development

COPY 1

AIRCRAFT NOISE

N79-77108

(NASA-CR-157440) CIVIL AVIATION RESEARCH AND DEVELOPMENT: AN ASSESSMENT OF FEDERAL GOVERNMENT INVOLVEMENT (National Academy of Engineering) 56 p

Unclas
00/84 18428

A report by the ASEB Ad Hoc Committee
Aircraft Noise

LIBRARY COPY

OCT 17 1969

LEWIS LIBRARY, NASA
CLEVELAND, OHIO

BEST AVAILABLE COPY

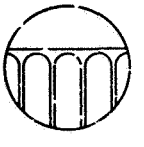
RECEIVED
MAY 1979
STI FACILITY
ACCESS DEPT.

AERONAUTICS AND SPACE ENGINEERING BOARD
NATIONAL ACADEMY OF ENGINEERING

18428

CIVIL AVIATION RESEARCH AND DEVELOPMENT

An Assessment of Federal Government Involvement



AIRCRAFT NOISE

AERONAUTICS AND SPACE ENGINEERING BOARD
NATIONAL ACADEMY OF ENGINEERING
Washington, D.C.
December 1968

The study and report by the Aeronautics and Space Engineering Board of the National Academy of Engineering were supported by the National Aeronautics and Space Administration under Task Order Contract NSR 09-012-912.

Available from

Aeronautics and Space Engineering Board
National Academy of Engineering
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

The study and report by the Aeronautics and Space Engineering Board of the National Academy of Engineering were supported by the National Aeronautics and Space Administration under Task Order Contract NSR 09-012-912.

Available from

Aeronautics and Space Engineering Board
National Academy of Engineering
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

The National Academy of Engineering was established in December 1964. The Academy is independent and autonomous in its organization and election of members, and shares in the responsibility given the National Academy of Sciences under its congressional act of incorporation to advise the federal government, upon request, in all areas of science and engineering.

The National Academy of Engineering, aware of its responsibilities to the government, the engineering community, and the nation as a whole, is pledged:

1. To provide means of assessing the constantly changing needs of the nation and the technical resources that can and should be applied to them; to sponsor programs aimed at meeting these needs; and to encourage such engineering research as may be advisable in the national interest.

2. To explore means for promoting cooperation in engineering in the United States and abroad, with a view to securing concentration on problems significant to society and encouraging research and development aimed at meeting them.

3. To advise the Congress and the executive branch of the government, whenever called upon by any department or agency thereof, on matters of national import pertinent to engineering.

4. To cooperate with the National Academy of Sciences on matters involving both science and engineering.

5. To serve the nation in other respects in connection with significant problems in engineering and technology.

6. To recognize in an appropriate manner outstanding contributions to the nation by leading engineers.

X2-00

C-64006-B

Foreword

The National Academy of Engineering established the Aeronautics and Space Engineering Board (ASEB) in May 1967 to advise the National Aeronautics and Space Administration (NASA) and other government agencies. In consultation with officials of NASA, the Department of Transportation, the Federal Aviation Administration, the President's Science Adviser, certain interested committees of Congress, and the National Aeronautics and Space Council, as well as other government and private groups, the Board selected as its first topic of study, "Civil Aviation Research and Development: An Assessment of Federal Government Involvement." The Board's report under that title was published on August 13, 1968. It summarizes reports of six ad hoc committees, including this report by the Committee on Aircraft Noise.

As background information for the reader of the committee reports, the most important conclusions and recommendations of the Board are stated below (summary report, pages v-vi).

> The Board has concluded that in a favorable economic climate civil aviation can continue to flourish; in fact it can accelerate its beneficial growth if a carefully conceived program of planning and research and development aimed specifically at the civil air transport system is carried out.
>
> After considering the multiplicity of factors affecting the growth of civil aviation, the Board concluded that the three most critical factors are (1) airport and support facilities, (2) noise, and (3) air traffic control.
>
> The most important recommendation of the Board pertains to knitting together more tightly the civil aviation research and development activities of the Department of Transportation, its major operating unit, the Federal Aviation Administration, and the National Aeronautics

and Space Administration, and especially to dividing their responsibilities according to capability. The DOT should provide the leadership in conducting systems studies to identify, analyze, and rank civil aviation goals as well as the research and development needed to attain these goals; NASA should be responsible for research and development in all the areas of importance to civil aeronautics; the FAA should, in addition to operating the airways network, be responsible for the systems testing of the resulting operational concepts and hardware.

The Board's report also contained many detailed technical recommendations concerning research and development needed to ensure the continued growth of civil aviation. These pertain to most of the important areas of civil aviation, including systems and the specific areas of flight vehicles, aircraft operations, air traffic control, airport and support facilities, economics, and noise.

The Board assigned detailed work to six ad hoc committees covering the above specific areas. Each committee was composed of knowledgeable men from different parts of the aviation community; their valuable contributions are sincerely appreciated by the Board.

Board membership is listed in Appendix I. The Board wishes to express its appreciation and indebtedness to a large number of individuals beyond its membership with whom it conferred. These are also listed in Appendix I. The Board is indebted to the American Institute of Aeronautics and Astronautics, the American Society of Civil Engineers, the American Society of Mechanical Engineers, the Institute of Electrical and Electronics Engineers, and the Society of Automotive Engineers for conducting special studies, making available special reports, and identifying members for participation in an advisory capacity. The cooperation of these societies served to broaden the advisory base.

The Board is particularly grateful for the valuable assistance provided by the members of the Ad Hoc Committee on Aircraft Noise, who are listed on the following page.

AD HOC COMMITTEE ON

AIRCRAFT NOISE

OF

THE AERONAUTICS AND SPACE ENGINEERING BOARD

Chairman: William D. Neff
Director, Center for Neural Sciences
Indiana University

Leo L. Beranek (ASEB)
President
Bolt Beranek and Newman Inc.

Raymond L. Bisplinghoff (ASEB)
Dean, School of Engineering
Massachusetts Institute of Technology

Kenneth M. Eldred
Director of Research
Wyle Laboratories

William J. Galloway
Vice President
Bolt Beranek and Newman Inc.

John B. Large
Chief, Aircraft Noise Unit
The Boeing Company

Robert Lee
Acoustics Consulting Engineer
Aircraft Engine Group
General Electric Company

Ronald G. Schlegel
Head of Noise Abatement Section
Sikorsky Aircraft, Division of
United Aircraft Corporation

Contents

INTRODUCTION 1

DISCUSSION OF PROBLEMS AND RECOMMENDATIONS

General Considerations 5

Technical Considerations 15

APPENDIXES

I. CONTRIBUTORS 31

II. BIBLIOGRAPHY 41

Introduction

Organization for Conduct of the Aircraft Noise Study

The members of the Committee on Aircraft Noise were selected on the basis of their knowledge and experience in various areas of research and development related to aircraft engines and airframes, including rotor craft, acoustical physics, psychoacoustics, and noise measurement techniques. In addition, all of the members are associated in some degree with other government or professional groups active in the noise field.

Method of Conducting the Study

At its first meeting, the committee heard brief reports on activities of other groups engaged in studies on noise, including the Committee on Supersonic Transport (SST)-Sonic Boom and the Committee on Hearing, Bioacoustics, and Biomechanics of the National Academy of Sciences and the Committee A-21 on Aircraft Exterior Noise Measurement of the Society of Automotive Engineers. The committee also reviewed and discussed other current publications, including a special report on aircraft noise prepared by the American Institute of Aeronautics and Astronautics and a survey of current and potential noise problem areas influencing the development of civil aviation, prepared by an industrial research organization for the ASEB. Further information and assistance were provided by the Society of Automotive Engineers and the American Society of Mechanical Engineers.

In order to consider as many as possible of the important elements of the aircraft noise problem without unnecessarily duplicating any recent or current investigations, the committee obtained permission from the NAS Committee on SST-Sonic Boom to include in this report the recommendations of that committee's three panels.

With this and other background information, members of the committee drafted a report that was reviewed and approved by the committee at its final meeting on February 19, 1968.

Background

During the early phases of the ASEB study, the discussions by experts in the various fields of civil aviation and the review of Senate Document Number 90, "Policy Planning for Aeronautical Research and Development," prepared by the staff of the Library of Congress, led to the identification of major problems that are either already restricting the growth of civil aviation or that are expected to limit the growth of aviation in the future. Among the problems cited were congestion of the airways and airports with related traffic control difficulties, safety, aircraft noise, and sonic boom associated with supersonic flights. Although attention has been given to these problems, they still remain as potential retarding influences on the growth of civil aviation.

In addition, the members of the Aircraft Noise Committee either had served on an Ad Hoc Jet Aircraft Noise Panel of the Office of Science and Technology or were familiar with its report, "Alleviation of Jet Aircraft Noise Near Airports," published in March 1966. The committee was of the opinion that the conclusions and recommendations of the OST panel remained valid and were so considered by the committee as it prepared this report.

For additional background information, the committee reviewed the papers resulting from the International Conference on the Reduction of Noise and Disturbance Caused by Civil Aircraft held in London in November 1966. These papers covered technical problems as well as the economic and administrative issues that make the aircraft noise problem so complex.

Scope of the Study

This survey of aircraft noise problems should be read with the recognition that other ASEB ad hoc committees were active in the following areas:

Flight vehicles and airbreathing propulsion
Aircraft operations
Air traffic control
Airport and support facilities
Economics of civil aviation

The committee identified the basic problems involved in aircraft noise and recommended research and development necessary to resolve these problems. In some cases, the committee has suggested agencies that it considered appropriate to carry out or participate in the recommended research and development. In its summary report, the Board generally chose to omit any such references, thus giving the agencies concerned the option of determining appropriate implementing activities.

The committee discussed several general issues involving aircraft noise and made technical recommendations in the areas of noise generation and propagation, flight operations for fixed-wing and V/STOL aircraft, noise criteria, land use, and sonic boom. These topics are presented in the following sections of this report.

Discussion of

Problems and Recommendations

Results of the committee's study have been divided into two major sections. The first, "General Considerations," presents views on issues and goals and discusses the responsibilities of groups concerned with aircraft noise abatement. In the section on "Technical Considerations," the committee reviews the state of the art and recommends research and development necessary to hasten progress toward solution of the aircraft noise problem.

GENERAL CONSIDERATIONS

This section discusses aircraft noise as an important factor in the growth of civil aviation, identifies major issues and short- and long-range goals for achieving a viable air transport system that will limit noise to acceptable levels, and finally describes the roles and accomplishments of government, industry, and universities in dealing with problems of aircraft noise.

The growth of civil aviation brought about by the introduction of jet aircraft has been accompanied by a worldwide concern for the noise they produce. Table 1 illustrates the way in which these noise levels were raised with each successive introduction of new generations of transport aircraft.

It is likely that the introduction of some of the new generations of transport aircraft might produce even higher noise levels in neighborhoods under flight paths or to the sides of runways. These noise levels most certainly will be accompanied by increasing frequency of operation, which will result in longer duration of high noise levels in neighborhoods adjacent to airports.

The noise problems associated with civil aviation are beginning to receive attention from airframe and engine

INTENTIONALLY BLANK

Table 1

Comparison of Maximum Perceived Noise Levels Measured During Takeoff and Approach for Various Transport Aircraft

Aircraft	Year[a]	Typical Maximum Gross Weight, pounds	Noise Levels, PNdB	
			Takeoff[b]	Approach[c]
Douglas DC-3	1936	27,000	98	96
Douglas DC-6B	1951	100,000	106	106
Boeing 707-120	1959	250,000	129	117 (50^{o} flaps)
Boeing 707-320B	1963	330,000	130	121 (40^{o} Flaps)

a. Year of introduction into widespread airline service.

b. As measured under the flight path at 15,000 ft from start of takeoff roll with the aircraft at maximum gross weight and with no power cutback for noise abatement purposes. Sea level and standard day conditions are assumed to exist. A power cutback to a 3-deg climb angle results in a 6-PNdB (perceived noise decibels) reduction for the Boeing 707-120 and a 1-PNdB reduction for the Boeing 707-320B.

c. As measured under a 3-deg glide-angle approach path, 1 mile from touchdown with normal approach flight conditions.

manufacturers, airport operators, government agencies, and the public. The complex relationships developed between the air transport industry and the communities surrounding airports as a result of aircraft noise will become a major obstacle to the growth of aviation if the problems of noise exposure and its effects on operations cannot be resolved.

It is clear that any solution to the noise problem must include the development of quieter aircraft; the establishment of federal noise criteria and of noise standards for aircraft; the full utilization of operational procedures for aircraft noise abatement in the vicinity of populated areas; the adoption of consistent land-use practices in communities surrounding air terminals; and the development of low- and moderate-cost air-conditioning and soundproofing techniques for housing in these areas. These problems are evidenced by the difficult situations now existing at many major commercial jet airports, and they could become even more pronounced around V/STOL (vertical or short takeoff and landing) terminals and under V/STOL flight corridors unless new solutions are found.

In approaching a solution to the noise problem, the committee believes that industry and government must resolve these basic issues:

1. The absence of government-established noise criteria for aircraft certification and appropriate land use has produced confusion in the air transport industry. Thus, insufficient political and economic incentives have been offered to manufacturers and operators of aircraft and to airport managers to make full use of existing technology and to develop new technology and operating procedures for achieving lower aircraft noise exposures and developing proper land use in the vicinities of airports.

2. Although substantial empirical knowledge and some scientific theories exist concerning the sources of aircraft noise and the technology for its partial control, the scientific basis for understanding the primary noise-generating mechanisms is incomplete. Research now underway in this country is not in most instances aimed at the fundamental physical problems of jet noise generation and propagation, but is instead conducted primarily at the engineering level and consists largely of trial-and-error attempts to reduce noise. There is an almost total absence of basic research in physical acoustics that would further our understanding of jet noise. There is also a serious shortage of qualified research scientists to undertake such research programs; of those who are capable of doing the needed research, few are being adequately utilized.

3. The lack of an overall analysis of the civil air transportation system up to the present time has prevented a proper allocation of the responsibilities required to achieve lower noise exposures. In this regard, the committee noted a current industry-sponsored study of the system composed of aircraft, airlines, airports, and airport communities that is aimed at determining the relationship between aircraft noise exposure, cost, and other factors involved in the aircraft noise problem. This type of study is a necessary first step in resolving the problems now existent and those about to be incurred with future commercial fixed-wing jet aircraft. There remains an urgent need for a government-supported analysis of the total air transportation system, including the social and economic aspects, before new types of aircraft, including V/STOL

aircraft, begin extensive operations over major metropolitan areas.

4. Suitable low- and medium-cost air-conditioning equipment, building materials, and construction techniques do not exist for controlling noise inside houses located in neighborhoods with high aircraft noise exposure. Research and development programs are necessary to evolve products and to provide guides for architects and builders. Progress made in this direction must be recognized as only a partial solution to the aircraft noise problem since these measures will be effective only when the individual is restricted to the confines of his home.

Recommended Goals

In the opinion of the committee, the first step to be taken in attacking these issues is the identification of goals as a means of coordinating the research and development efforts of government, industry, and universities in a systematic approach to the overall problem of aircraft noise.

The fundamental goal of those concerned with the noise from aircraft operations is the provision of an air transportation system that will yield acceptable noise levels in populated areas while simultaneously meeting safety, convenience, and economic criteria. When the lead time necessary to institute any significant changes in new aircraft and engine designs is considered, it should be clear that selected goals must be established and implementing actions started immediately if any effect is to be realized over the next ten years.

The committee does not imply that achieving the suggested goals will solve the aircraft noise problem or remove the need for a continuing long-range research and development program. Rather, these goals should be regarded as a means of achieving temporary solutions to the immediate problems, with the recognition that any research leading to new aircraft and engine configurations is not likely to produce tangible results in less than four to eight years.

Actions to achieve the following sets of one-year and three-year goals should begin immediately.

One-year Goals

1. Establish interim noise certification requirements for future fixed-wing transport and general aviation jet aircraft. These requirements will of necessity be based on existing technology and present knowledge of aircraft and engine performance characteristics and noise criteria. Consideration should be given to a possible retrofit potential on existing aircraft, but not necessarily to the levels applicable to the new designs.

2. Define and establish optimal flight procedures for existing aircraft in order to provide minimum noise exposure from the operations of both commercial and general aviation aircraft.

3. Develop within the appropriate federal agencies the necessary scientific and technological capabilities to define, direct, and administer adequate internal as well as external contract programs for research and development aimed at reducing aircraft noise or protecting the public from exposure to excessive noise.

4. Implement a coordinated, federally supported contract research and development program to study aircraft noise with the goal of reducing it at its source or of protecting the public from excessive exposure.

5. Define and implement a grant or contract program involving universities and directed at the development of curricula that will increase the supply of scientific and engineering personnel who are properly educated to work in the fields of science and engineering that deal with the problems of aircraft noise.

6. Develop within the appropriate military agencies a basic policy that low noise levels are an important requirement for all future flight vehicles and power plants and that military specifications associated with the development and procurement of future advanced propulsion systems or components should consistently reflect this requirement.

Three-year Goals

1. Develop techniques that will make possible a reliable prediction of noise-generating characteristics of

aircraft and engine configurations that are to be employed in future aircraft designs.

2. Perform an overall analysis of the air transportation system that will lead to more stringent certification requirements for all aircraft designs. These requirements should be developed not only on the basis of aircraft and engine technology but should also consider the effects of total air terminal operations, community response to noise, and adequate land-use planning. Particular emphasis should be given to the problems associated with metropolitan area V/STOL operations and sonic booms produced by supersonic aircraft.

3. Develop and validate, at least on a preliminary basis, improved psychological and sociological investigative methods so that the effects of noise on communities can be assessed with considerably more accuracy than is presently possible.

4. Develop adequate technical understanding and educational programs necessary to formulate preliminary public administration procedures at all levels of government for implementing proper land-use allocation in the vicinity of air terminals.

5. Develop model building codes to provide for adequate noise-control measures in buildings constructed within high noise-exposure areas.

Primary Roles of Government, Industry, and Universities

One can divide the participants concerned with development of aircraft noise control techniques into three general groups: government, industry, and universities. Government includes federal, state, and municipal agencies. Industry includes airframe and engine manufacturers, airlines, terminal operators, and the consulting organizations that provide supporting research and development. Universities include all undergraduate- and graduate-level institutions capable of providing education in science and engineering disciplines relevant to the study of noise.

While each of the three above-named responsible groups has many cross-linked secondary roles, we believe that the primary role that each should play is as follows:

Government

The federal government should establish criteria for allowable aircraft noise, community response measures, and procedures for adequate land-use planning. It should provide itself with appropriate in-house technical competence in order to (1) formulate policy based upon an understanding of technical knowledge, and (2) pursue sufficient internal research to maintain a sound scientific basis for decisions involving technical questions. It should also provide the financial support for those research and development programs that are not within the economic capability of industry. Financial support should be broadly considered, not only in the form of direct contracts for research and development efforts, but also as part of an analysis of the air transportation system, considering the economic impetus of fare structures, subsidies, and other elements that government agencies have within their control.

Historically, most commercial aircraft propulsion systems have been derivatives of prior military systems, in which there has been no mission requirement for noise control. Consequently, in nearly all the major advanced development work on aircraft engines in the past fifteen years, technological competition to reduce noise was not present and the technical base necessary to support efforts to achieve a practical solution to the problem of noise abatement was not adequately established.

With the increasing concern about aircraft noise, military agencies can indirectly assist in the identification and solution of potential noise problems of civil aviation by requiring, as part of the contract specifications for development of propulsion systems or components for new aircraft, that the contractor perform noise analyses and measurements on the systems or components.

State and municipal governments should encourage the establishment of public administration criteria that will lead to the development of zoning, building codes, and other procedures that will ensure adequate land-use planning in high noise-exposure areas.

Industry

The elements constituting the aircraft industry should recognize noise as a primary factor at the initiation of

preliminary design studies and thus should perform basic and applied research. They should apply the results of research and should develop the engineering procedures necessary to yield the technology required to build and operate aircraft that will meet established criteria.

Universities

Some universities should develop educational programs that will equip scientists and engineers to conduct research leading to (a) a better understanding of noise creation and propagation, (b) technical advances that will reduce noise at the source, and (c) techniques and procedures that will help to eliminate noise as an element of environmental pollution.

Are the Principal Protagonists Doing Their Job?

In the previous section we have identified primary roles for three major groups that have responsibility for dealing with problems of aircraft noise. A summary indication of how well they are doing is provided below.

Government

Although much discussion has taken place over the last few years, no cohesive government research and development or public policy program on aircraft noise has yet fully evolved. For a number of years, NASA, FAA, and the Federal Housing Administration (FHA) have had modest research and development programs that have come about largely through the efforts of individuals within these agencies.

While NASA has competent technical personnel in the areas of physical acoustics, aircraft engines, and structures, it has a limited in-house capability to assess on a scientific basis the psychological and sociological elements related to aircraft noise. The FAA has sponsored a modest applied research program for some four or five years. The lack of a well-defined agency plan and a limited in-house technical capability have severely restricted the efficacy of the FAA programs in aircraft noise research. Although the FHA has made some theoretical studies and is providing limited support for experimental efforts aimed at evaluating current

application of building techniques as a means of reducing aircraft noise inside houses near airports, no program has been undertaken to develop necessary low- and medium-cost structures, equipment, and techniques for controlling this noise.

NASA is currently conducting noise research in its laboratories, and both NASA and DOT (FAA) are supporting additional noise research through contracts with industry. These research efforts are important, and support for them should be continued and expanded. In this regard, the committee noted the planned increase in the NASA noise research programs for fiscal year 1969 to $20 million, more than double the $9.5 million spent in fiscal year 1968. However, this projected increase still falls short of the minimum $36 million level recommended by the committee for research and development in noise generation and propagation.

Of equal concern to the committee is the lack of attention given to basic research in physical acoustics relevant to an understanding of the generation and propagation of noise in jet streams. Such programs will require not only money but also the identification of the limited number of qualified investigators in the United States and possibly abroad who could undertake these fundamental studies.

Industry

The airframe and engine manufacturers, responding to the particular interest of NASA, FAA, and the public in aircraft noise reduction, have expended millions of dollars over the past ten years in an attempt to develop aircraft and engine configurations that will generate less noise for given thrust. As a result of the lack of established governmental criteria for acoustic performance, the attempt to construct quieter aircraft has come about for a variety of reasons, including the desire of customers, competition among manufacturers, and regulations imposed by certain communities. The absence of a real scientific understanding of the basic mechanisms of noise generation has hindered progress toward technical solutions of the aircraft noise problem. The shortage of college graduates adequately trained in this field has been another retarding factor in establishing a vigorous research and development program. Limited funds for basic research has been another.

In a situation in which responsibility for noise control has not been defined by agencies of the federal government, airport operators, in general, have done very little to conduct studies that could lead to useful regulations around their airports. There are a few notable exceptions, such as the actions taken by the Port of New York Authority (PNYA), the London Airport Authority, the Orly (Paris) Airport, and the Los Angeles International Airport. The original PNYA regulation governing operations of jet aircraft from its airport and airline concern about aircraft noise were major factors in the effort to provide for quieter aircraft and for operating procedures that reduce noise. The efforts of most airport operators to promote meaningful land-use allocation in the vicinity of their airports have been largely futile. The lack of public-administration procedures to enable the recommendations of planners to be implemented is at least partly responsible for this futility.

The building industry has not had sufficient incentive to initiate programs for developing new building materials and techniques and low-cost air-conditioning equipment to reduce noise inside dwellings.

Universities

For more than a decade within the United States there has been a serious neglect of programs to provide for the education of scientists and engineers equipped to do research or apply results of research that might help solve the problems of aircraft noise. With a few modest exceptions, universities do not provide good educational programs in physical acoustics related to engineering problems associated with aircraft. Only a few individuals in university psychology departments have been interested in problems associated with human response to noise pollution of the environment. Again, only a few psychology departments have prepared undergraduate or graduate students with a knowledge of psychophysics or social psychology so that they might contribute to the solution of problems of establishing noise criteria or to the study of individual or community response to noise. The committee is unaware of any interdisciplinary activity within universities in this country that brings together aerodynamicists, acoustical physicists, psychological and physiological acousticians, and social

scientists to consider the problem of aircraft noise, or more generally, the problem of environmental noise pollution.

TECHNICAL CONSIDERATIONS

The committee discussed at some length the present state of knowledge in a number of areas affecting the development of commercial aviation insofar as it is influenced by noise problems. This section summarizes the committee's views and presents suggestions on research and development requirements to alleviate the problems of aircraft noise.

State of the Art and Requirements for Research and Development

The committee identified the following as the most important areas needing increased technical effort: jet noise, turbomachinery noise, helicopter and V/STOL external and internal noise, and criteria for evaluating noise response. Although some progress is being made, the committee believes that an expanded research and development effort will be necessary in each of these areas to provide suitable and timely solutions for all aspects of the aircraft noise problem.

Jet Noise

Two areas of concern for jet noise suppression are the high-speed jet stream ($\bar{V}_{jet}$* > 2,000 ft/sec) produced by the engines of the SST and the relatively low-speed jet stream ($\bar{V}_{jet}$ < 1,500 ft/sec) generated by current turbofan engines. The existing theories of generation and propagation of jet noise are mainly appropriate for jet velocities between 1,500 and 2,000 ft/sec; these theories help to explain the characteristics of the mixing-type suppressors developed for use on early turbojet engines. Recent research has shown that the sources of noise for jets of both high and low velocity are different from those in the range of 1,500 to 2,000 ft/sec and that different techniques are required in order to obtain suppression (e.g., a mixing nozzle applied to a low-velocity jet can increase the noise output).

---

* Mean expanded jet velocity.

The approach to jet noise suppression must be reexamined both theoretically and experimentally and redirected toward a better understanding of noise generation.

During the last decade, ad hoc testing by the aircraft industry has produced a considerable amount of data on noise from jet engines (both with and without the use of suppressors), but only a small percentage of effort has been directed toward a systematic investigation of the noise sources in the jet and the mechanisms of jet noise reduction. As a consequence of this lack of fundamental research, there is no reliable method of designing noise suppressors for maximum acoustical performance with a minimum impairment of engine performance. Jet noise suppressors are designed largely by trial and error, and the results cannot be extrapolated to new types of jet engines that have very high or very low exhaust velocities. Academic research work has been confined to theoretical studies or to experimental studies on small air jets. Full-scale engine measurements are being carried out by industry in conjunction with a limited amount of theoretical work.

The major objectives in jet noise research are an understanding of the mechanisms of jet noise generation and quantitative descriptions of how radiated noise and aerodynamic mixing characteristics of jets are related and how they are both dependent on the geometric configuration and flow parameters of the nozzle or suppressor. The information required includes (1) the identification of noise sources so that their locations in the jet and the relative roles they play in the production of acoustic power may be better understood, (2) systematic empirical data derived from tests of a variety of nozzle-suppressor configurations, and (3) the correlation between aerodynamic and acoustical characteristics of the jet and the geometric features of the nozzle-suppressor design. This kind of research investigation is deemed vital to any attempt to develop rational design guides for jet noise suppressors. In addition, consideration of nozzle internal and external aerodynamic performances must be made an integral part of the design and test effort in any jet noise suppressor development program.

Much information has been gathered on the propagation of noise through the atmosphere and along the surface of the earth, but only the coarser parameters of the atmosphere

that affect propagation have been considered. Such parameters as surface temperature, humidity, and wind velocity are certainly of prime importance, but consideration of only these parameters greatly limits accuracy in predicting the propagation characteristics of noise that is also affected by wind gradients, turbulence characteristics of the atmosphere (particularly near the ground), and properties of the earth surface. Research is needed in this area so that more accurate estimates can be made of noise propagation.

Turbomachinery Noise

No method exists that completely identifies the physical principles of noise production in a rotor-stator set. Most research work to date has concentrated on the propagation characteristics of the noise. Until the aerodynamic characteristics of the blades can be related to the noise generation, design of a quiet compressor will be a matter of trial and error, and predictions of engine noise output will be educated guesses. The theoretical aspects of this problem have been largely ignored by basic scientists. Research workers have not made the kinds of measurements that will help define the source of noises in the compressor. This is a difficult problem but one that can be solved by scientific research.

Engineering data have been gathered in the past eight years on the design of acoustic liners for compressor noise suppression. But the physics of the problem – such as the propagation of high-intensity noise through the moving turbulent medium, and the energy dissipation, in a porous material, of high-intensity noise superposed on airflow – has received little attention. Until basic research is done in this area, we can never exploit the full potential of the acoustic liner in the design of an engine.

Research and development work on turbomachinery noise has been carried out on a limited scale, but it has been directed toward the attenuation of noise during propagation along a duct, rather than toward the identification of noise generating mechanisms and the development of techniques to modify these mechanisms.

Current noise-reducing techniques rely mainly on engineering data for the design of sound-absorbing linings in ducts with airflow. The data are based largely on

measurements carried out by the airframe and engine manufacturers in moderate airflows and for moderate sound intensities. The absorbing mechanisms need to be better understood, and the data should be extended to include examination of the effects of high-intensity sound. Some study of the propagation modes in ducts has been made by the engine manufacturers, and the results are being used in the design of rotors and stators.

Investigation of the noise-generating mechanisms has been restricted to rotor-stator interaction and to measurements of the aerodynamic loads on the rotor blades. However, the mechanisms of noise generation associated with even these effects are not fully understood.

It is important that the noise-generating mechanisms be identified so that the compressor and turbine can be designed to meet minimum noise criteria. A research program is required to study in detail the parameters that influence noise generation, e.g., rotor-stator interaction, rotation speed, blade shape, and tip separation. Experimental work will require the development of suitable instrumentation to permit the measurement of the aerodynamic parameters.

The study of noise attenuation by porous linings requires extension to include high-intensity sound waves and the investigation of aerodynamic devices for improving the absorptive properties of the linings in high-speed airflow. Two approaches – study of noise generation and study of noise absorption – are necessary if significant reductions in compressor noise are to be achieved.

Helicopter and V/STOL External Noise

Based on acoustical considerations, it is anticipated that the V/STOL aircraft* in commercial operation during the next decade will be a combination of pure helicopters, compound helicopters, and stowed-rotor types of vehicles. Present technology indicates that noise problems for close-in operation may severely limit the acceptance of direct-lift jets and high disk-loading propeller-type vehicles for the

*This does not apply to aircraft such as the DeHavilland Otter or McDonnell-188, which approximate STOL-type performance and whose acoustical properties are more comparable to those of conventional propeller-type aircraft.

commercial intercity and intracity markets until methods can be devised to make them considerably quieter than they are today.

The most identifiable and most annoying feature of some types of helicopter and V/STOL aircraft is the impulsive noise, commonly referred to as blade slap, which can be generated under conditions of blade vortex interaction, critical Mach number, and severe blade stall. Research into the phenomenon of blade slap has demonstrated that each of the above factors by itself or in combination with others can cause blade slap noise. A second problem sometimes involved with the conventional helicopter is the nonimpulsive rotational (and vortex) noise generated by the main and antitorque-producing tail rotor blades. As the disk loading and tip speed of either of these rotor systems are increased, both types of noise (nonimpulsive rotational and vortex) increase and become more objectionable.

As the size of the helicopter increases, so does the size of the engine system for supplying the power. Inlets and exhausts of turbine engines then become major sources of noise.

For helicopter types of V/STOL aircraft the following appears necessary:

1. A better understanding of the causes of blade slap noise must be gained so that proper steps can be taken in the design stages to minimize it. In this regard, blade vortex geometry and its effect on blade slap must be better defined, and the effects of critical Mach number and blade stall on blade slap must also be better understood. Analytical, model, and full-scale studies appear necessary for this research. Much more work is required before there can be assurance in the design stages that blade slap will not be a limiting characteristic.

2. More laboratory and field tests are necessary to better define the "noisiness" or "annoyance" of impulsive blade slap noise. Psychoacoustic studies to date have not dealt adequately with problems involving impulsive noises.

3. More wind-tunnel and full-scale tests are necessary to determine the effects of blade tips on reducing rotor noise. Recent evidence indicates that altered blade design can reduce noise by as much as 7 dB, with improved performance due to the decreased loss of energy.

4. More study is necessary to improve the definition of helicopter rotor blade directivity patterns, particularly during forward flight. Specifically, the effect of the forward flight on the directivity of vortex-generated noise has not been adequately explored.

5. Research is required to develop relationships between noise level and variation in operating procedures (land, takeoff, and cruise) for major V/STOL vehicles.

The above research is also necessary for compound and stowed-rotor types of vehicles. In addition, the following work is needed to maintain acceptable noise levels for the larger versions (100-passenger sizes, for instance) of these V/STOL vehicles:

1. The study of higher-strength materials for fuselage and structural components should be accelerated. As gross weights decrease, so in general does the noise.

2. Further research is needed to understand how propeller noise is generated. This would make possible better prediction of noise to be expected from particular propeller designs. In particular, correlation between measured and predicted levels of some types of V/STOL propellers seems to be very poor. Theoretical studies and empirical measurements are required before adequate methods are available either to predict or to control the noise associated with new V/STOL propeller designs.

Helicopter and V/STOL Internal Noise

The internal noise of helicopters and V/STOL aircraft is also a serious problem. In the case of the single-rotor helicopter, where the main transmission is only a few feet from the ears of the passengers and where the skin and frame structure radiate a considerable level of acoustic energy, more research is needed on techniques to reduce the noise at the source. In particular, methods of gear noise reduction and gear box isolation need further development. In the case of tandem machines, an additional problem may arise in the section of the cabin that is exposed to the near-field radiation of the main rotor blade tips where they intermesh or pass near each other. Additional research into efficient methods of reducing low-frequency main rotor blade passage noise (15 to 100 Hz) is desirable. The same kind of research is also necessary for vehicles with propeller

tips passing close to the fuselage; in the latter case, the noise will be in a somewhat higher frequency range (100 to 400 Hz).

Criteria for Evaluating Response to Noise

A primary psychoacoustic problem in evaluating the human response to aircraft noise is the selection of physical measures of noise that are most useful in the development of scales to assess human reactions to the noise. Over the past ten years most of the work in psychoacoustics related to aircraft noise has been concerned with the application of the perceived noise level concept. The early work on perceived noise level, or PNdB, had to do with the relative "noisiness" of aircraft noise as judged in comparison to bands of random noise. The results of these studies provided a fairly reliable means for computing a numerical noisiness value for the relatively smooth, well-behaved random spectra as produced by propeller-type and later by turbojet aircraft. Little initial consideration was given to such factors as the structure of the sound wave in terms of its time history, its duration effects, the presence of impulsive spectra, and the tonal components of the noise. The operational use of jet aircraft in which compressor noise became noticeably apparent and the development of fan engines prompted further investigations of the PNdB concept to account for the judged relationships of aircraft noises in which tonal components were present. Work also was performed on evaluating the effect of duration of the time pattern of a flyover. Empirical correction factors for such duration effects have been identified in laboratory tests. Some studies have also been made on the effects of the addition of tones superimposed on a random spectrum. Several methods have been proposed for predicting the increased judged noisiness of sounds when tones are present. Current work is being pursued to combine the effects of level and duration with spectral irregularity, i.e., tonal components, into a measure that is presently called "effective perceived noise level." No consensus is yet available on the details of appropriate calculation procedures for such a measure, although there seems to be general agreement that corrections to the basic PNdB must be made when tones or duration effects are of concern.

Little work has been done on the pronounced Doppler effects that occur during flyovers of aircraft in approaches where strong tonal components from compressors and fans are observed. There is some suspicion that the shape of the time pattern of a flyover affects in noisiness. No careful psychoacoustic studies have yet been performed to clarify this aspect of the problem, nor has any suitable method been developed for taking into account multiple noise events in estimating subjective reaction under controlled laboratory conditions. Almost all laboratory judgments used in the development of psychoacoustic measures have been concerned with flyovers simulating either takeoff or approach of jet or turbofan aircraft. Little work has been done on the more complex sounds associated with large helicopters. For some purposes, the present forms of PNdB seem appropriate for use in correlating judgments of noisiness with speech interference for relatively well-behaved helicopter sounds. There is some evidence, however, to indicate that impulsive sounds superimposed on the normal noise produced by the helicopter (e.g., sounds such as those produced when blade slap is present) are not adequately accounted for in present PNdB calculation procedures. Careful investigation of these effects is required.

Psychoacoustic measures are generally obtained by comparing different sounds in a laboratory environment. Pilot studies have been performed to extrapolate from a strictly laboratory environment to a pseudo-field environment. For example, judgments have been made comparing the noisiness or acceptability of aircraft and motor vehicle sounds in a pseudo-field environment. This consists essentially of moving the subjects from the laboratory into the field, but the environment is still artificial when compared to normal living conditions. The methodology for extrapolating psychological reactions from laboratory or contrived field experiments to the reactions of a populace as a whole is in a very unsatisfactory state. The two primary means for examining community reaction in the past have been through a study of the noise exposure as it relates to complaints received from community residents or through the correlation of noise exposures with the results of social surveys conducted in communities surrounding airports. At the present time, for reasonably well-behaved sounds, laboratory experiments provide relative judgments of the

noisiness of various sounds with standard deviations of the order of 2 dB. Studies of community behavior, on the other hand, through either the complaint-analysis approach or through social surveys, show standard deviations in expected response of the order of 5 to 12 or more dB. Clearly, greater certainty in the prediction of community response is to be desired.

The ability to assess how a community will respond to a given noise exposure is hampered by the lack of adequate social-psychological tools to perform reasonable analyses. While a number of social surveys have been conducted in the past, they all have followed similar patterns. At present, some social psychologists believe that new and more precise tools for measuring reaction must be developed if the variance obtained in sociological investigations of community response is to be reduced. It is important that these tools be developed as quickly as possible if there is to be any hope for obtaining other than a cursory evaluation of community response to noise.

One of the major difficulties in developing valid community noise criteria is the restricted ability to identify those other elements of community response to noise that are not physical dimensions of the noise. A better quantitative assessment must be made of the effects of fear, air pollution, nuisance, and other nonnoise elements of aircraft operations that influence community reaction. For example, the noise from aircraft in some instances may be objectionable only because it signals a source of potential danger from the aircraft passing overhead.

The community studies being done under contracts supported by NASA and the FAA represent an effort to achieve some of the objectives listed above.

Recommendations for Research and Development Programs

The following section summarizes the research and development recommendations discussed previously. These recommendations are intended as a guide primarily for the government agencies concerned with the aircraft noise problem, including NASA, DOT and FAA, and the Department of Housing and Urban Development (HUD).

Noise Generation and Propagation

1. Jet Noise.

a. Identify the noise-producing mechanisms and develop physical descriptions of jet noise in terms of appropriate flow and geometric factors for mean jet velocities less than 1,500 ft/sec and mean jet velocities greater than 2,000 ft/sec.

b. Pursue a noise-suppressor development program based upon knowledge gained from the above research.

c. Expand basic research efforts in physical acoustics, including programs to educate new investigators in this field.

2. Turbomachinery.

a. Identify and quantitatively describe the noise-producing mechanisms in terms of related geometric and aerodynamic parameters.

b. Identify and describe the modes of sound propagation internal to engine-nacelle configurations under conditions of high sound intensity, high temperature, and shock-wave generation.

c. Evaluate the noise-absorption characteristics of materials suitable for use in engine noise suppression. Develop new materials having higher absorption, lower weight, and increased service life.

3. Rotors and Propellers.

a. Identify sources of noise produced by V/STOL rotors and propellers, and describe these sources in terms of appropriate geometric and aerodynamic parameters.

b. Develop blade tip and multiple rotor configurations to minimize noise generation.

4. Prediction Methods.

a. Develop methods for accurately predicting the noise produced by vehicles in motion on the ground or in flight.

b. Make more extensive use of and solicit industry participation in flight programs conducted at existing NASA-FAA aircraft test ranges, such that data acquired from a specific test will be useful in other analyses.

c. Develop improved techniques for predicting noise propagation through the atmosphere in both air-to-ground and ground-to-ground cases.

5. New Concepts. Conduct design studies and exploratory experimental programs pertaining to advanced concepts in airframe and propulsion design, engine cycle selection, and the use of unconventional component design features that can directly or indirectly lead to lower noise production.

Flight Operations

1. Fixed-wing Aircraft Flight Procedures. Continue present studies of the effects of variations in takeoff and approach procedures on minimizing noise and concurrently consider their implications on air traffic control.

2. V/STOL Aircraft Flight Procedures. Develop flight procedures that will minimize noise exposure over populated areas, particularly for lower-altitude operations, consistent with safety and air traffic control requirements.

3. New Concepts. Continue present and proposed projects to develop direct-lift control and other means for increasing aircraft height over communities.

Criteria for Noise

1. Human Response.

a. Extend present knowledge of the physical parameters of sound that influence individual reactions to aircraft noise.

b. Develop psychoacoustic measures suitable for use in all aircraft and engine certification requirements.

c. Develop more accurate psychological and sociological techniques for predicting community response to aircraft noise.

2. Building Requirements.

a. Specify noise reduction requirements and appropriate building code recommendations to provide adequate control of aircraft noise inside new buildings.

b. Specify recommended land-use categories in terms of noise exposure and suitability for zoning of property for residential, commercial, industrial, and public assembly purposes.

Land Use

1. Analysis of Noise Exposure and Land Use.

a. Prepare estimates of noise exposure around all airports expecting major jet aircraft operations.

b. Develop procedures for estimating noise exposure produced by helicopter and other V/STOL operations.

c. Inventory land use around a selected set of existing airports (e.g., ten) and use these data to evaluate possible administrative and economic bases for altering usage to that more compatible with aircraft operations.

2. Education.

a. Implement an educational program on aircraft noise and land use for headquarters and field staffs of FAA and HUD to enable them to consult more adequately with local government agencies on aircraft noise problems.

b. Stimulate inclusion of subject matter pertaining to aircraft noise and land use in university curricula for architects, urban planners, and public administrators. Encourage universities to present symposia on aircraft noise and land use to local public officials.

3. Public Administration.

a. Develop recommended zoning practices and building codes for use by local authorities.

b. Develop educational, public relations, and economic aid programs to encourage local authorities to adopt appropriate zoning procedures and building codes.

c. Establish procedures requiring adequate noise analyses of all airport and heliport sites involving federal funds or operational approval.

Building Modifications

1. Structures and Techniques. Develop new means for modifying, at low and medium cost, the structures of various types of housing now existing near airports so that noise of aircraft operations will be reduced inside by 20 to 30 PNdB.

2. Air Conditioning. Develop economical means for introducing, at low and medium cost, air conditioning into existing houses near airports so that they will be comfortable after being closed off to exclude noise.

Sonic Boom

In order to complete its review of the major elements of the aircraft noise problem, the committee noted the current reports of the National Academy of Sciences Committee

on SST-Sonic Boom. The recommendations of its three subcommittees are summarized below:

Report on Generation and Propagation of Sonic Boom

The Subcommittee on Research was satisfied with the national program of research on generation and propagation of sonic boom now being carried out by government, industry, and universities with the following exceptions and comments:

1. More theoretical work, together with a program of controlled experiments in the laboratory and the full atmosphere, is needed on the problem of shock-wave propagation through turbulent atmospheric ground layers.
2. Topographical effects are not being given adequate research attention. A necessary first step in such research is the construction of a laboratory facility in which various types of topography may be simulated and studied.
3. Controlled laboratory and flight tests are recommended to test our ability to predict theoretically the effects of accelerations and maneuvers.
4. Design studies aimed at minimizing sonic boom should be continued by both government and industry with emphasis on unconventional as well as conventional aircraft configurations.
5. Emphasis should be given to the gathering of overall statistical overpressure and impulse data, relating it to the maximum extent possible to atmospheric, flight, and topographical conditions.
6. At the present time, future prospects for dramatic reductions in the intensities of sonic boom produced by supersonic aircraft are not readily apparent. The possibility that unconventional configurations may be devised that will yield significant reductions cannot be disallowed, but at present, the future must be viewed in terms of small reductions obtained through better understanding of theory, design refinements of conventional aircraft, and improvements in propulsive efficiency and operating procedures.

Report on Physical Effects of the Sonic Boom

The recommendations of the Subcommittee on Physical Effects are summarized below:

1. At least two types of sonic-boom simulators should

be immediately designed and constructed for testing panels on the order of 8 ft square of typical construction materials and cubic assemblies 20 ft on a side.

2. A physical response research program, comprising the following elements in descending order of importance, should be immediately undertaken and vigorously pursued:

a. Repetitive tests in simulators of a wide range of damage-susceptible materials and assemblies

b. Static and dynamic laboratory tests of commonly used glass and glass systems

c. Acceleration and expansion of sonic boom studies by the Environmental Science Services Administration

d. A count, by sample survey, of window panes in selected cities

e. Evaluation of environmental parameters of material and building responses to natural phenomena

f. Theoretical study of critical earth structures

3. An interdisciplinary group, including engineers and lawyers, should be appointed to study legal-structural considerations of commercial SST operations.

4. Contracts should be let to several competent firms specializing in instrument-data-recording-and-retrieval systems to propose the characteristics for an economical monitoring system and to accomplish preliminary cost-effectiveness analyses of the proposed system.

Report on Human Response to the Sonic Boom

The recommendations of the Subcommittee on Human Response are summarized below:

1. Develop a framework of analysis and of tools of measurement for an effective in-depth study of the advantages and disadvantages of overland SST flights.

2. Continue laboratory studies of the properties of the sonic boom most important to an understanding of such human reactions as annoyance and startle.

3. Renovate existing facilities where necessary and construct specialized new facilities for better simulation of sonic boom to involve additional qualified investigators who seek to make specific laboratory studies of human response to the sonic boom.

4. Study human response to the sonic boon during sleep.

5. Continue studies of reactions of individuals and of organized communities to overflights at different sonic-boom levels, if and when military overflight programs provide the opportunities for such studies.

6. Develop organizational arrangements and methodology needed to support the research proposed above.

Aeronautics and Space

Engineering Board

Appendix I

PAGE 30 INTENTIONALLY BLANK

Aeronautics and Space Engineering Board

H. Guyford Stever, Chairman
President
Carnegie-Mellon University

Raymond L. Bisplinghoff, Vice Chairman
Dean, School of Engineering
Massachusetts Institute of Technology

Leo L. Beranek
President
Bolt Beranek and Newman Inc.

Willis M. Hawkins
Vice President - Science and Engineering
Lockheed Aircraft Corporation

John M. Kyle, Jr.
Chief Engineer
The Port of New York Authority

Bernard M. Oliver
Vice President for Research and Development
Hewlett-Packard Company

Perry W. Pratt
Vice President and Chief Scientist
United Aircraft Corporation

Allen E. Puckett
Executive Vice President
and Assistant General Manager
Hughes Aircraft Company

George E. Solomon
Vice President and Director,
Systems Laboratories
TRW Inc.

PAGE 32 INTENTIONALLY BLANK

Edward C. Wells
Senior Vice President
The Boeing Company

Carlos C. Wood
Division Vice President - Engineering
Sikorsky Aircraft, Division of
United Aircraft Corporation

Contributors

The Aeronautics and Space Engineering Board gratefully acknowledges the willingness of the following leaders from government, industry, and the academic community to share with the Board their extensive knowledge in the various fields of civil aviation.

Mr. Frederick L. Bagby, Manager, Mechanical Engineering Department, Battelle Memorial Institute

Mr. W. V. Blockley, Principal Associate and Vice President, Webb Associates

Mr. Richard E. Carpenter, Senior Specialist, Science and Technology, Science Policy Research Division, Legislative Reference Service, Library of Congress

Dr. Paul W. Cherington, James J. Hill Professor of Transportation, Harvard Business School

Mr. William M. Crilly, Senior Vice President for Planning, Eastern Airlines, Inc.

Dr. Robert C. Duncan, Assistant Director for Systems, NASA Electronics Research Center

Mr. A. J. Evans, Director of Aeronautical Vehicles Division, Office of Advanced Research and Technology, National Aeronautics and Space Administration

Mr. William C. Fuchs, Assistant for Federal/International Aviation Matters, Office of the Chief of Naval Operations, U.S. Navy

Mr. James J. Gehrig, Staff Director, Senate Committee on Aeronautical and Space Sciences

Dr. Nicholas E. Golovin, Office of Science and Technology, Executive Office of the President

Mr. Karl Harr, Jr., President, Aerospace Industries Association of America, Inc.

Mr. Edward H. Heinemann, Vice President, General Dynamics Corporation

Mr. Richard Hutton, Vice President, Grumman Aircraft Engineering Corporation

Mr. Howard Kirshner, Technical Director, Air Transportation Systems, The MITRE Corporation

Mr. John W. Klotz, Assistant Director, Tactical Control and Surveillance Systems, Office of Director, Defense Research and Engineering, Department of Defense

Mr. Frederick A. Koomanoff, Senior Associate, Planning Research Corporation

Mr. Edwin A. Link, Director and Consultant, Ocean Systems, Inc., General Precision, Inc.

Mr. James P. Loomis, Columbus Laboratories, Battelle Memorial Institute

Major General J. C. Maxwell, USAF, Program Director, Supersonic Transport Program, Federal Aviation Administration

Mr. George R. Mellinger, Special Assistant, Systems Program Management, North American Rockwell Corporation

Mr. William C. Mentzer, Senior Vice President, Engineering and Maintenance, United Air Lines, Inc.

Mr. T. C. Muse, Assistant Director (Tactical Aircraft Systems), Office of Director, Defense Research and Engineering, Department of Defense

Mr. William T. Piper, Jr., President, Piper Aircraft Corporation

Mr. Jay W. Rabb, Deputy Director, National Airspace Program Office, Federal Aviation Administration

Colonel Stephen G. Saltzman, USAF (Ret.), Staff Coordinator, Transportation Workshop, 1967

Mr. David D. Thomas, Deputy Administrator, Federal Aviation Administration

Dr. Edward C. Welsh, Executive Secretary, National Aeronautics and Space Council

Mr. Charles A. Zraket, Vice President, Washington Operations, The MITRE Corporation

Professional Engineering Societies

Contributors

American Institute of Aeronautics and Astronautics

John K. Wimpress, Chairman	Chief of Aerodynamics, Commercial Airplane Division, The Boeing Company
Carlton W. Bristol, Jr.	Project Manager, Noise Reduction, Pratt & Whitney Division, United Aircraft Corporation
R. E. Coykendall	Engineering Department, United Air Lines, Inc.
D. L. Francis	Manager, Installation and Noise Control, General Electric Company
A. L. McPike	Chief, Acoustics, McDonnell Douglas Corporation
A. Richard Seebass	Associate Professor, Cornell University
Jim Rogers Thompson	Manager, Acoustics Department, Lockheed-California Company

American Society of Mechanical Engineers

Louis N. Rowley, Jr.	Publisher and Editor, Power Publications Division, McGraw-Hill, Inc., and President, ASME
Kenneth M. Foreman	Geoastrophysics Group, Research Section, Grumman Aircraft Engineering Corporation, and Liaison Representative, ASME

John deS. Coutinho	Special Assistant to the Vice President, Lunar Excursion Module of Apollo, Grumman Aircraft Engineering Corporation
T. P. Torda	Professor, Mechanical and Aerospace Engineering Department, Illinois Institute of Technology

Society of Automotive Engineers

R. H. Isbrandt	Vice President, Auto Engineering and Research, Auto Division, American Motors Corporation, and President, SAE
F. W. Kolk	Assistant Vice President, Engineering, American Airlines, Inc.
H. L. Martin	Research Manager, SAE

Bibliography

Appendix II

Bibliography

A. Noise

1. "A Discussion of Current and Potential Noise Problem Areas Influencing the Development of Civil Aviation," draft report 1618, Bolt Beranek and Newman Inc., February 1968.

2. "Report on Generation and Propagation of Sonic Boom," NAS-NRC Committee on SST-Sonic Boom, October 1967.

3. "Report on Physical Effects of the Sonic Boom," NAS-NRC Committee on SST-Sonic Boom, February 1968.

4. "Report on Human Response to the Sonic Boom," NAS-NRC Committee on SST-Sonic Boom, June 1968.

5. "Aircraft Noise," Leo L. Beranek, Proceedings of Conference on Effects of Noise on Man -- A Health Hazard, Public Health Service, Washington, D.C., June 14, 1968.

6. Sources referred to in correspondence from Ken Foreman, ASME:

(a) "The Constraining Order of Airport Noise," E. J. Richards, ISAV report No. 148, July 1966, NASA doc. N67-18369.

(b) "The Effects of Acoustic Feedback on the Spread and Decay of Supersonic Jets," January 23, 1968, AIAA paper No. 68-80.

7. "Alleviation of Jet Aircraft Noise Near Airports," report of the Jet Aircraft Noise Panel, Office of Science and Technology, March 1966.

8. "Alleviation of Aircraft Noise," N. W. Golovin, Astronautics and Aeronautics, January 1967, Vol. 5, pp. 71-75.

PAGE 43 INTENTIONALLY BLANK

9. "The Speech Interference Effects of Aircraft Noise," C. E. Williams, et al., September 1967, FAA DS-67-19.

10. "The Noisiness of Tones Plus Noise," K. S. Pearsons, R. D. Horonjeff, and D. E. Bishop, September 1967, NASA CR-1117.

11. "Concepts of Perceived Noisiness, Their Implementation and Application," K. D. Kryter, Journal of the Acoustical Society of America, 1968, Vol. 43, pp. 344-361.

12. "Land Use Planning Relating to Aircraft Noise," Bolt Beranek and Newman Inc., October 1964. Also published by DOD as "Land Use Planning with Respect to Aircraft Noise," AFM 86-5, TM 5-365, NAVDOCKS P-98. Also Appendix A, May 1965.

13. "Techniques for Developing Noise Exposure Forecasts," SAE Research Project Committee R25, August 1967, FAA DS-67-14.

14. "A Study – Insulating Houses from Aircraft Noise," Bolt Beranek and Newman Inc., May 1967, HUD TS19.

15. "The Economics of Aircraft Noise Suppression," F. B. Greatrex, September 1966, ICAS paper 66-5.

16. "Standard Values of Atmospheric Absorption as a Function of Temperature and Humidity for Use in Evaluating Aircraft Flyover Noise," 1964, SAE ARP 866.

17. "Noise Measurement Evaluations of Various Takeoff-Climbout Profiles of a Four Engine Turbojet Transport Airplane," W. L. Copeland, et al., 1966, NASA TND-3715.

18. "Suppression of Jet Noise with Emphasis on the Near Field," K. M. Eldred, et al., Wright-Patterson AFB, 1963, report ASD-TDR-62-578.

19. "Possibilities and Devices for the Suppression of Jet Noise," E. Grande and J. B. Large, February 1968, Boeing doc. 6-20609. Paper presented at course on "Noise

Generation and Suppression in Aircraft," University of Tennessee Space Institute, January 1968.

20. "An Experiment to Locate the Acoustic Sources in a High Speed Jet Exhaust Stream (Preliminary Results)," R. C. Potter and J. H. Jones, Journal of the Acoustical Society of America, 1967, Vol. 42, p. 1214.

21. "The Development of Engineering Practices in Jet and Compressor Noise," A. O. Andersson, E. Grande, and J. B. Large, AIAA Fourth Propulsion Joint Specialist Conference, Cleveland, Ohio, June 1968.

22. "Optimization of Duct Linings for Sound Attenuation," F. Fischer and A. O. Andersson, January 1968, Boeing doc. D6-29356 TN.

23. "Effects of Increased Inlet-Guide-Vane-Rotor Spacing on Compressor Noise Reduction," W. L. Copeland and J. L. Crigler, Journal of the Acoustical Society of America, 1966, Vol. 40, p. 1249 (A).

24. "The Development of Engineering Practices in Jet, Compressor, and Boundary Layer Noise," J. B. Large, Symposium on Aerodynamic Noise, Toronto, Canada, May 1968.

25. "Reduction of Compressor Noise Radiation," M. V. Lowson, Journal of the Acoustical Society of America, January 1968, Vol. 43, No. 1.

26. "Study of Aircraft in Short Haul Transportation Systems," The Boeing Company, January 1968, NASA CR-986.

27. "Summary and Analysis of Related Feasibility-Study Designs of V/STOL Transport Aircraft," W. J. Deckert and D. H. Hickey, October 1967, AIAA paper No. 67-938.

28. "Noisiness Judgments on Helicopter Flyovers," K. S. Pearsons, January 1967, FAA DS-67-1.

29. "NASA-Lockheed Short-Haul Transport Study," R. Scherrer, et al., Conference on V/STOL and STOL Aircraft, National Aeronautics and Space Administration, April 1966, NASA SP-116.

30. "Helicopter Rotor Noise Generation and Propagation," R. Schlegel, R. King, and H. Mull, October 1966, USAAVLAES Technical Report 66-4.

31. "Vertical Takeoff Aircraft for Metropolitan and Regional Service," C. C. Wood, October 1967, AIAA paper No. 67-940.

32. "Some Views on Civil Aeronautical Research and Development," a special AIAA report consisting of working papers developed for the use of the ASEB, February 1, 1968.

33. "Individual and Community Reaction to Aircraft Noise: Present Status and Standardization Efforts," W. J. Galloway and H. E. VonGierke, London Noise Conference, November 1966.

B. General

1. "The Jumbo Jet and Public Safety," Jerome Lederer, Journal of the Royal Aeronautical Society, April 1968.

2. "Global Air Transport Accident Statistics," A. M. Lester, ICAO Bulletin, January 1967.

3. "Unresolved Civil Aeronautics Problems," Walter Tye, Journal of the Aerospace Sciences.

4. FAA Air Traffic Activity, Calendar Year 1967, published by the Department of Transportation, Federal Aviation Administration, February 1968.

5. "How the Airplane Designer Can Help the People in the Cockpit," George S. Schairer, presented to the Society of Automotive Engineers, New York, April 26, 1967.

6. "Flight Safety in the New Jet Era," Norbert E. Rowe, Astronautics and Aeronautics, September 1966.

7. "Annual Review of U.S. General Aviation Accidents," National Transportation Safety Board, Department of Transportation, November 1967.

8. "How Safe is Air Travel?" Frank Leary, Space/Aeronautics, May 1968.

9. "Survival in the Air Age," a report by the President's Air Policy Commission, January 1, 1948.

10. "Long Range Planning for the Air Traffic System," Radio Technical Commission for Aeronautics, March 17, 1967, DO 135.

11. "The United States Supersonic Transport – A Progress Report, "John M. Swihart, The Boeing Company, AIAA paper No. 67-750.

12. "Kelly Johnson on the Future," Technical Information Service, AIAA.

13. RTCA Annual Report, 1967.

14. RTCA – Air Traffic System – Current Air Traffic Control Problems and Recommended Improvement Program, June 1963, 54-63/DO 120.

15. "Policy Planning for Aeronautical Research and Development," a staff report by the Legislative Reference Service, Library of Congress, for the Senate Committee on Aeronautical and Space Sciences, May 19, 1966, Doc. No. 90.

16. "Aeronautical Research and Development Policy," hearings before the Senate Committee on Aeronautical and Space Sciences, January 25-26, February 27, 1967.

17. "Science, Technology, and Public Policy During the 89th Congress," a report of the Subcommittee on Science, Research, and Development of the House Committee on Science and Astronautics, 90th Congress, Serial G.

18. "Technology Assessment," a statement by Emilio Q. Daddario, Chairman of Subcommittee on Science,

Research, and Development of the House Committee on Science and Astronautics, 90th Congress, Serial I.

19. Statistical Handbook of Aviation, FAA, 1966.

20. General Aviation, A Study and Forecast of the Fleet and Its Use in 1975, FAA, July 1966.

21. Aviation Forecasts, Fiscal Years 1967-1977, FAA, January 1967.

22. Aviation Demand and Airport Facility Requirement Forecasts for Large Air Transportation Hubs Through 1980, FAA, August 1967.

23. "Transportation Facts and Trends," Transportation Association of America, Fifth Edition, April 1968.

24. Air Transport Facts and Figures, 1967, Air Transport Association.

25. "Maintenance of an Adequate Airport System," hearings before the Aviation Subcommittee, Senate Committee on Commerce, 90th Congress, August 28-31, 1967.

26. The National Airport System, Interim Report, Aviation Subcommittee, Senate Committee on Commerce, January 23, 1967.

27. "Aeronautical Research and Development Policy," report of the Committee on Aeronautical and Space Sciences, United States Senate, January 31, 1968.